Blockchain for 5G and IoT: Opportunities and Challenges

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Abstract-Hitherto, the evolution of mobile networks have fulfilled the increasing demands for enhanced performance, availability, portability, elasticity, and energy efficiency posed by the ever growing network services. In line with the progression, 5G depicts the next generation of mobile networks that further promises remarkable performance improvements as well as creation of new value chain. In parallel to 5G, the Internet of Things (IoT) has emerged as another new paradigm for interconnection of massive communication-capable heterogeneous smart objects. 5G is envisaged to broaden IoT's scope and fields of applicability. However, since current mobile networks and also more general IoT systems are based on centralized models thus it is anticipated that they will face tremendous challenges to meet-up the requirements of future 5G-enabled-IoT use cases. To solve these inevitable issues Blockchain stands out as promising technology. Some of the offerings of Blockchain technology are immutability, non-repudiation, proof of provenance, integrity, privacy, etc. Blockchain's combination with 5G and IoT still requires essential insights with respect to concrete application domains, scalability, privacy issues, performance, and potential financial benefits. The paper aims to elaborate and emphasize the key aspects of the use of Blockchain for 5G and IoT.

Index Terms—Blockchain, Cyber Physical Systems (CPS), Internet of Things (IoT), Industrial Internet

I. INTRODUCTION

Last couple of decades have witnessed remarkable evolution both in the space of Internet as well as mobile communications. Looking at the evolution of the Internet, the journey so far is marked by five different phases [1]. It emanated from local computer networking aimed at sharing of expensive resources to WWW (World Wide Web) which enabled sharing of soft information, globally. Then came the phase of mobile-Internet which opened the use of mobile networks to access Internet while connected devices are on the move. Next arrived the phase of social networks where people started making use of Internet to stay connected and share their stories. The current phase is of the Internet-of-Things (IoT) that provides means to connect almost all kind of physical objects to the Internet. Today, IoT is swiftly penetrating the global network space by enabling connectivity of devices ranging from tiny consumer-devices to heavy industrial machines. Thus, IoT has the potential to radically transform the way automation is perceived at the (physical) object level. IoT offers exciting new avenues especially for industries, since it intrinsically supports the much required Machine-to-Machine (M2M) Communications. Standardization bodies are eagerly looking into such kind of M2M communications [2]. The evolution of mobile networks marked its inception in the year 1980 as first generation (1G). The communication system

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then was completely analog and merely supported the country wide wireless voice calling. With 2G, digital systems (GSM) hit the market and thus the services like text message were introduced. It was the 3G which provided mobile broadband with high speed web browsing and video streaming along with the required level of security. The current generation is 4G came into existence in year 2010 and it enhanced date rate, reduced the latency, enabled seamless live video streaming, provided better QoE, etc. Next, the mobile communication industry is ready for 5G.

The need for 5G is primarily driven by two broad requirements; first is need for broadband services and second is need of wireless ecosystem that can underlay and handle variety of IoT applications. The expected characteristics of 5G networks are super high data rate (e.g., peak data rate of 100 Gbps), extremely low latency (e.g., order of 1 ms), ubiquitous connectivity for massive number of devices, immersive experience for VR/AR applications, less cost per bit, low operational cost and ameliorated QoE.

The advancements in IoT and the soon arrival of 5G, have popularized the development of 5G-enabled-IoT applications. Such applications pose stringent requirements such as high capacity, assured privacy & security, scalability of heterogeneous applications, ultra low latency, optimized use of network resources, efficient energy management, low OPEX, etc. In this paper, our concern revolves around the issues that arise from the the anticipated massive growth in the number of connected devices and traffic volume resulting from 5G and IoT use cases. Despite the fact that the security architectures that are currently being used for mobile networks and generic IoT systems match the required expectations, they are in principle centralized [3], [4], [5]. Using such centralized security solutions for 5G and 5G-enabled-IoT applications will lead to various impediments like increased cost due to inherent heterogeneity, complex and static security management procedures, over-utilization of network resources, creation of bottleneck in the network, single point-of-failures, high OPEX, etc. Thus, using centralized security solutions for 5G and IoT driven applications not only struggle to meet the demands but also adversely affect the projected visions of 5G and IoT.

In this context, Blockchain technology turns out to be a promising building block as it can provide solution to all security related issues in a unified and decentralized way. To appreciate the possible business value that can be achieved with the underpinning of Blockchain technology for 5G and IoT, it is worth looking at their estimated individual business values. On the one hand, a recent Gartner study predicts that



Fig. 1. A typical transaction flow in blockchain

\$3.1 trillion of business value will be created by Blockchain by 2030 [6]. On the other hand, IoT's global market is estimated to reach at \$457 billions by 2020 [7], and by 2030, IIoT will add \$14.2 trillion value [8]. Whereas, 5G will add business-to-business value of \$700 billion by 2030 [9]. Therefore, it is worth exploring the opportunities and challenges pertinent to the use of Blockchain as decentralized security and privacy solution for both 5G and IoT.

The rest of the paper is organised as follows. Section II provides a quick overview on the 5G, IoT, and the Blockchain. Section III explains the significant challenges in the 5G and IoT contexts. Section IV illustrates the values that Blockchain brings in for 5G and IoT. Section V elaborates the new challenges in the Blockchain and IoT integration, with some related works to address these challenges. Section VI concludes the paper.

II. BACKGROUND

A. 5G

5G, the next era of mobile networks, will mark the significant jump in the realm of wireless communication. ITU-R (Radio-communication Sector), which is one of the three sectors of International Telecommunication Union (ITU), has defined three broad services for 5G as eMBB (enhanced Mobile BroadBand), mMTC (massive Machine Type Communication), and URLLC (Ultra Reliable and Low Latency Communications) [10]. To support such varied kind of services, 5G is characterised by ultra low round-trip latency (of order of 1 ms), high data rate (of order of 10 Gbps), high scalability (of the order of 100x connected devices), etc. The key enabling technologies for 5G are Network Slicing (NS), SDN (Software-Defined Networking), MEC (Multiaccess Edge Computing), NFV (Network Function Virtualization), mmWave communications, massive MIMO, Device-to-Device (D2D) connectivity, etc. Evidently, IoT is going to be one of the prominent use cases of 5G which would make use of mMTC and URLLC types of services.

B. IoT

Undoubtedly, IoT is transmogrifying the way physical objects connect and communicate; from proprietary way of locally-connected devices to standardised way of globally connected objects. IoT has fueled the intercommunication of massive number of heterogeneous and resource-constrained physical objects at Internet scale. With IoT, connectivity is feasible among anyone and anything using any network for any available service irrespective of time and place. IoT involves M2M or M2H-telecommunications-based sensing and monitoring, followed by efficient data storing and processing (using technologies like Artificial Intelligence (AI), Big Data analytics, Cloud Computing, Mobile Edge Computing (MEC), etc.), and finally making decisions and effectuating actions leading to the next level of automation.

Two broad categories, widely talked about IoT are massive IoT (mMTC - massive Machine Type Communication) and mission critical IoT. The former, needs more consideration primarily on scalability, while, the later has stringent demands in terms of ultra low reliability and very low latency [11]. Smart city, smart agriculture, smart home, gaming, etc. are some of the examples of massive IoT, whereas, Industrial IoT (IIoT), remote surgery, IoT enabled autonomous vehicles, tactile internet, etc. are the examples of mission critical IoT.

C. Blockchain

Blockchain, a distributed ledger technology enables users to interact and transact (store and retrieve data) with ensured data authenticity, immutability, and non-repudiation. The distributed nature of Blockchain allows the industrial entities and various 5G/IoT devices to exchange data, to and from their peers, eliminating the centralized operational requirement. The Blockchain-assisted 5G ecosystem is capable of establishing accountability, data provenance, and non-repudiation for every user. The first block in a Blockchain is referred to as the genesis block, which does not contain any transaction. Each block thereafter contains a number of transactions and linked as a chain with the consistency of digital signatures. Figure 1 illustrates a typical transaction flow of Blockchain when integrated with a business system.

III. GENERAL CHALLENGES OF 5G IOT

A. Scalability

Both 5G and IoT rely on some cloud-based architecture for their control and management. Or in other words, a centralised cloud processes the data generated by the network nodes and sends control signals back to the network nodes to implement some action like fault management, resource (re)allocation, traffic engineering, routing, etc. But with the increasing number of these devices and the enormous amount of data they are generating it would be an impending task for the centralised cloud servers to scale up their capacity and computing power. Furthermore, both for the IoT and 5G scenarios, the devices connect to the cloud through a gateway or an edge node through a series of networks termed as fronthaul, midhaul, and backhaul. With the number of devices trying to connect to the cloud, often these links in the fronthaul, midhaul, and backhaul networks immediately adjacent to gateway nodes become congested.

B. Lack of Auditability and Control over data sharing/usage

In an IoT network a huge amount of data is generated and they are generated from devices that are proprietary to several enterprises. Most of the times these data are therefore not under the control of all the parties involved. By all parties, it can refer to all equipment vendors whose hardware form a network node, or all service providers who share a common physical network infrastructure or all users who share a common cloud platform. Thus, it is difficult to manage and audit these data in terms of who owns them, where from they are generated and how they can be processed.

C. Data Silos

As discussed in the previous subsection, the data generated in the networks have different ownership and are highly noncoherent and hence are hard to trace and audit. Sometimes, there are also no common standards and protocols defined for these data to be exchanged between different devices owned by different entities. Moreover, because of trust issues, even within the different units of an enterprise, data could either be locked in or may not be inter-operated because of different communication standards and protocols. Sometimes similar types of data, for example, let us say, weather and climatic data, collected by different organisations are also not shared or inter-processed to come up with an unified decision.

D. Security and privacy

In both 5G and IoT domains, the devices are usually handheld lightweight devices with low power and form factor. In case of some IoT application scenarios, the devices are even more low power capable with the ability to run on battery power for ages. Because of this, sometimes security of these devices are seriously at risk. These devices have low to nil security features embedded into them. Furthermore, because of fierce competition of deployment, both equipment vendors and network service providers compromise the security aspect. Therefore, home sensors, ambient-assistedliving sensors, healthcare monitors, and any other devices that contain location information can easily be compromised and sensitive users' data can go to malicious third parties. Furthermore, when the data generated by millions of devices send their data to the cloud for storage and processing, the 'locality of information' gets lost and there is always a chance of that information getting compromised from shared cloud servers.

E. Heterogeneity in device resources

In a 5G/IoT context, depending on the application and the segment of the network, the nodes can have variable computational powers with some nodes having a few watts of power driven by a battery and a few megabytes of memory. This is a problem because some devices may prove to be a bottleneck in terms of its operating lifetime. For example, a sensor network might be totally out of function if one node near the gateway cannot process a huge amount of packets or have no battery life and totally gets switched off.

F. Complex interactions of different OS/software stacks/hardware

The devices in an 5G/IoT network are part of different technology standards with different air interfaces, with different signalling schemes, different PHY and MAC layer protocols, data rates, modulation and coding schemes etc. They also run on different operating systems. With these plethora of protocols and standards coexisting, it is been difficult to define a common communication standard between all the devices. It is also difficult to build a system and program it that consists of a variety of devices with different communication protocols and OS. Sometimes, this aspect limits the application scenarios for devices and also limits the range of device types to be used for a particular use case.

IV. WHAT BLOCKCHAIN CAN BRING TO IOT

A. Trust Building

The establishment of trust is one of the most significant requirements in most of the industries. The stakeholders including the hosts and consumers of a particular service such



Fig. 2. Blockchain service capability on 5G IoT context

as electronic financial ecosystem or healthcare management system require trust in different dimensions. The criteria of the trust defined as regulatory enforcement and globally shared in most of the industries. For instance, in the financial context Payment Card Industry-Data Security Standards (PCI-DSS), Health Information Portability and Accountability Act (HIPAA), and General Data Protection Regulation (GDPR) are the examples of the regulations to the establishment of trust. The smart contracts are identifiable as the trust representatives of the regulatory definitions in action. The smart contracts can be defined as software codes enforcing the regulatory criteria and make them transparently available. The transparency of the smart contract ensures the trust to all the stakeholders and guarantee that the regulatory requirements are accurately defined in the smart contracts and executing perfectly as per the regulatory requirements of the trust. For the IoT context, the deployment of smart contracts make the nodes "trusted" and compliant in the specific business ecosystem. Kuo et. al [12] explained the benefits of the usage of Blockchain-based smart contracts in the healthcare domain. Dagher et al. [13] and Yue et al. [14] explained the application of Blockchain for the access control of healthcare data. Yu et al. [15] described the establishment of trust in the IoT ecosystem using the Blockchain. Bahga and Madisetti [16] presented a Blockchainbased platform for the Industrial Internet of Things utilized for manufacturing.

B. Accelerated Data Change

The accelerated data change with higher throughput and minimal latency is an indispensable requirement of the modern IoT ecosystems. The performance of the entire system depends on the accelerated operation of data change in the IoT nodes. The distributed nature of Blockchain and smart contracts transform the data change landscape towards decentralization by elevating the performance features. For instance, the centralized validation of a particular data can be eradicated by validating by the smart contracts deployed on the IoT node itself or near the IoT nodes such as the edge or the fog-computing nodes which act as Blockchain network tenants. The requestresponse round trip lead time corresponding to data validation, manipulation or access can be drastically diminished using the decentralized smart contracts which will increase the performance of the ecosystem by higher throughput and minimized latency. Dorri et al. [17] proposed a Blockchain platform which supports scalability and lightweight in nature. Androulaki et al. [18] presented the performance elevation capability up to 3500 transactions per second with lower latency in Hyperledger Fabric along with multiple techniques.

C. Lower Costs

The operational costs of an IoT ecosystem can be minimized in multiple aspects when the Blockchain and smart contracts are utilized. The decentralized operation of smart contracts and the ledger eliminate the requirement of deploying expensive high-end computing infrastructure such as multi-core cloud computing nodes for concurrent transaction processing. Furthermore, the centralized data storage can be eliminated by the utilization of the distributed ledger instead of centralized databases. The data transmission overheads for the request round trips to the centralized nodes such as cloud instances in the centralized systems can be eliminated in the Blockchainbased smart contracts associated ecosystems. The efficient data usage is a vital requirement in any IoT-based system including the solutions connected to 5G. However, the IoT system incurs some data overhead for the synchronization between the nodes. Ibba et al. [19] illustrated the applicability of Blockchain in the smart city scenario and discussed the cost saving capabilities of such applications. Clauson et al. [20] explained a few use cases of Blockchain highlighting the cost-cutting benefits.

D. Improved Security

Confidentiality, Integrity, and Availability are the principal model of information security which is also known as the CIA triad. Keeping the confidentiality aside, the integrity and availability are the key features in the Blockchain-based smart contracts by design. The Blockchain-based smart contracts ensure the integrity by applying hashing and extending to the digital signatures to the individual transaction and maintaining the chain of trust entirely within the Blockchain. Furthermore, the Blockchain technology utilizes cryptographic techniques such as Merkle trees to ensure the consistent integrity over the network. Yu et al. [21] investigated the typical security and privacy issues in the IoT context and also elaborated by devloping a framework for the integration of Blockchain and IoT for the assurance of various functionalities including authentication and scalability. Khan et. al [22] explains the significant security issues in the IoT and how the Blockchain can address these issues. The availability is ensured by the distributed operational nature of the Blockchain network. For instance, Denial-of-Service attacks (DoS) attackers who attempt to conquer the Blockchain network have to overcome computationally difficult hurdles such as hijacking 51 percent of the mining power of the network and so on.

The privacy is an optional feature for the Blockchainbased smart contracts. The smart contracts highly focused on the transparency of the ledger. However, there are different privacy enforcement mechanisms that exist in the smart contract applications. For IoT, the smart contracts have versatile applicability to the privacy enforcement mechanisms such as efficient dynamic key exchanges and so on. Rodrigues et al. [23] proposed a design to mitigate Distributed-Denial-of-Service (DDoS) attacks applying Blockchain technology and smart contracts. Ouddah et al. [24] explained FairAccess, and Pinno et al.[25] presented access control applications for IoT using Blockchain. Dorri et al. [26] explained the elimination of DDOS attacks and linking attacks using Blockchain on the smart home IoT use case. Rahulamathavan [27] proposed a privacy-preserving Blockchain architecture utilizing attributebased encryption techniques.

Blockchain's strong protection against data tampering helps prevent a rogue device from disrupting synergy of communication systems involving home, factory or transportation system by injecting or relaying pernicious information. Thus, the Blockchain technology holds the potential to securely unlock the business and operational values of 5G networks to support common tasks, such as sensing, processing, storing, and communicating information. Ayoade et al. [28] proposed a way to utilze the Blockchain to access control the IoT data and store the raw encrypted data in Intel SGX secure enclaves. Dwivedi et al. [29] proposed a novel framework to enable features such as access control and enforce privacy for the IoT devices and medical data in the healthcare context. Kravitz and Cooper[30] explained the use of Blockchain technology for the identity management in IoT. Minoli and Occhiogrosso [31] presented a broad explanation of Blockchain in different contexts including the enforcement of IoT security.

E. Ensure the Accountability

Accountability is one of the key strengths of Blockchainbased smart contracts. The distributed ledger provides capability to transparent record keeping of the events logged and the ledger is protected against alterations with the utilization

of digital signatures. Some Blockchain platforms consider faster retrieval of the event log as a major requirement and optimize the retrieval operations further to ensure the compatibility of IoT ecosystems. The ledger is accessible with reduced overheads from either the IoT node itself or the edge-computing node which also acts as the Blockchain node with minor overheads. However, the accountability, guaranteed integrity, and the local invocation of the ledger elevates the value of Blockchain rather than the ordinary database systems in the IoT domain. Li et al. [32] explained the applicability of Blockchain for the IoT data storage and accountability. Liang et al. [33] explained the application of public Blockchain with a cloud server to ensure the data integrity of drone systems. Boudguiga et al. [34] investigated the utilization of Blockchain for the enforcement of the security services including accountability.

F. Immutability

The immutability is regarded as a principal strength of the Blockchain-based smart contracts. The distributed ledger as well as the smart contracts are computationally infeasible to alter according to the Blockchain design principles. For an intruder or a group of intruders, it requires to vanquish more than 51 percent of the computing power to manipulate the ledger, transactions or blocks. The 51 percent taking over the block generation power is either computationally or financially harder depending on the Blockchain network. (Some Blockchain platforms such as Ethereum charge for the computational power consumed). This attack is called as 51percent attack or majority attack in the Blockchain terminology. In the IoT perspective, the risk level is comparably low for the majority attacks due to the computational power limitations of the IoT infrastructure.

G. A More Efficient Supply Chain

The contribution of the Blockchain-based smart contracts to the supply chain data provenance is important in the IoT context. Brody [35] projects some high-level insights of the application of Blockchain and its revolutionary impact to the supply chain industry while Petersen et al. [36] illustrates a comprehensive review on the opportunistic scope of the Blockchain in the supply chain and logistics context. Kshetri [37] explained the applicability of Blockchain to achieve the supply chain management objectives such as reduced cost, improved quality, and risk reduction. Saberi et al. [38] critically examined the Blockchain and smart contracts with the potential in the supply chain management. The distributed ledger can be utilized as the transparent record which indicates the significant milestones in delivery chain of a particular commodity. The more concrete examples are supply chain of frozen foods, special commodities such as gemstones, and aircraft components. The main value of the integration of Blockchain for the supply chain is that the end consumer is capable of verification of the delivery of a particular commodity to ensure the compliance. For instance, in the frozen food supply chain, the IoT devices with temperature sensors are deployable to transmit the data corresponding to the temperature condition of the frozen products. The consumer is capable of retrieving the ledger upon the purchase and make sure whether the supply chain of the product is compliant with the temperature requirement. The integration of IoT for the supply chain makes the operation more efficient and transparent with improved value to the supply chain. Abeyratne and Monfared [39] proposed application of Blockchain for the manufacturing supply chain. Madhwal and and Panfilov [40] explained the applicability of Blockchain for the improved reliability of aircraft spare parts supply chain traceability.

H. Automation via Smart Contracts

The Blockchain with IoT is ideal for the automation requirements in the future industry. The smart contracts execute automatically when the conditions have reached to the executable state without intervention of any other party. The Blockchain and smart contracts deployed in the IoT devices are capable of executing the smart contracts and log the events in the distributed ledger. For instance, the temperature adjustments of the perishable cargo can be executed through the smart contracts based on the external temperature. Furthermore, the location-based customs duty calculation is operable through the smart contracts. Griggs et al. [41] proposed a system which utilizes private Ethereum Blockchain and master-slave modeled medical device deployment model to operate IoT powered medicine actuators accurately. Gallo et al. [42] introduced BlockSee, which is a Blockchain-based video surveillance system to validate and ensure the immutability of camera settings as well as the surveillance videos in the smart cities.

I. Decentralization

The decentralized operation is a core feature of Blockchain. The Blockchain operates with the decentralized transaction validation and approval mechanism. Furthermore, the transaction ledger is decentralized and each node contains a copy of the ledger. In contrast with the centralized storage and validation systems, the intruders require more effort to take over the control of decentralized validation systems and the decentralized ledger. The blocks of transactions are cryptographically linked and it is hard to alter them due to the decentralization. Huang et al. [43] proposed a decentralized solution for trusted data exchange using Blockchain for IoT and evaluated a prototype using the Ethereum Blockchain platform. The IoT ecosystems can ensure the service availability by utilizing the decentralized Blockchain systems.

V. CHALLENGES IN BLOCKCHAIN AND IOT INTEGRATION

A. Storage capacity and scalability

The consistent storage of transactions and blocks is a primary requirement of the Blockchain technology. Theoretically, each node must contain a copy of the ledger which is growing with the transactions. From a scalability perspective, the impact on storage for the IoT ecosystem will affect the functionality of the entire system. Especially, the evolving transactions with scaling up the system requires significant storage.

B. Processing Power and Time

There are a few computational-resource-intensive operations on the Blockchain ecosystem. These operations include transaction verification and block generation, which include few cryptographic operations. Due to the resource restricted nature of IoT, there are certain limitations in computation which will lead security risks. Therefore, application of the less resource intensive alternatives require to be applied specifically when the Blockchain is applied in IoT context. The Elliptic Curve Cryptography (ECC) related technologies are one of the significant alternatives, which incurs less computational overheads to the resource restricted IoT hardware. The cryptographic operations in the restricted hardware will occur performance limitations when scaling up the system.

C. Security

The integrity, availability, and access control are the primary security concerns in any system. However, the Blockchain enforces integrity and availability inherently by design. Each transaction is verified with the digital signature and the blocks of transactions linked with verifying digital signatures. The transaction verification is a resource intensive operation due to the limitations of IoT computing infrastructure. The transaction verification and block generation will have scalability limitations in cryptographic operations on Blockchain implementation. Kumar and Mallick [44] described the security and privacy issues in IoT and whhat is the significance of Blockchain in this context. Shafagh et al. [45] introduced a primary design of a distributed, secure data-storage system developed for IoT with moderated overhead in the system. The system enforces fine-grained access control and sharing of time-series sensor data in the IoT applications. Novo et al. [46] proposed a Blockchain-based access management architecture for IoT. The proposed architecture eliminates the communication overheads and improves scalability. Sharma et al. [47] proposed a Blockchain-based distributed cloud architecture to address the issues such as high availability, realtime data delivery, resilience, and low latency. The proposed solution incorporated Software-Defined Networking (SDN), fog computing, and Blockchain to enable low-cost and lowlatency access to the data in a secured manner.

D. Privacy

The massive volume of IoT devices is typical in modern deployment models. The IoT devices expose broader threat surfaces and significant limitations in privacy enforcement due to the resource-restricted hardware. Especially, when the Blockchain is considered, the data privacy is not inbuilt since the transactions are appended to the ledger publicly upon verification. Privacy preservation is a significant challenge with widely used encryption techniques. However, the lightweight cryptographic mechanisms developed for the resource-restricted computational infrastructure will be the

 TABLE I

 Summary of 5G IOT use cases, applicability of Blockchain and pertinent challenges

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Application	Description	Applicability of blockchain	Challenges
Smart city	Smart cities are the implementation of advanced modern	The Blockchain is ideal to enable the services such as	The computational power requirement for mining is
	techniques in the urbanization to improve the quality of	payments, e-Governance, security, and surveillance of the	a significant drawback in the Blockchain for IoT in
	human life.	smart cities.	the smart cities.
Smart home	The smart homes essentially need to automate the entire	The Blockchain and 5G IoT applicable for different use	The data privacy is a major problem. Hijacking the
	home environment comprising of home appliances and	cases such as smart home monitoring, remote accessing,	smart contracts will cause requirements.
	devices	energy optimization, surveillance and so on.	
Healthcare	All sorts of medical healthcare (preventive, diagnostic,	The Blockchain is applicable for the patient monitoring,	A malicious attacker can take over all mining nodes
	rehabilitation, etc.) demand monitoring, detecting symp-	automated treatments, healthcare data access control.	and this can be disastrous.
	toms, early diagnosis, logging privately medical history,		
	etc.		
Autonomous	Fully automated (level-5) vehicles require accurate sens-	There are different use cases for the electric vehicles,	The security and access control mechanisms require
vehicles	ing and processing with ultra low latency which is indeed	automated toll calculation, and other services.	to eliminate session hijacks and requires to ensure
	aligned with the promise of 5G IoT.		data privacy of individual users.
AR/VR	The interactivity, the experience of immersiveness and	The Blockchain is applicable to incentivize the users in	The interoperability of Blockchain and the existing
	practical application of AR/VR can be enhanced several	gaming and entertainment activities.	VR IoT applications is a significant requirement.
	folds with the combined visions of 5G and IoT.		
Industrial	HoT can revolutionize the way industrial manufacturing,	There are a lot of applications of industrial IoT and 5G	The scalability, data privacy, and data storage over-
IoT	supervision, resource management, etc. are carried out.	with Blockchain including smart manufacturing, auto-	heads are significant challenges in the industrial 5G
		mated maintenance, warehousing and so on.	IoT context.
Smart	To increase the agricultural productivity while minimiz-	The Blockchain is usable in smart agriculture to enable	The data integrity is highly important aspect of the
agriculture	ing the cost need continuous ambient parameter acquisi-	the lifecycle transparency, autonomous management, and	agri foods which requires a special attention on the
	tion, smart aggregation, and processing of large volume	establish regulatory requirements of agri foods.	ledger.
	of date is required.		
UAV	On the one hand, UAVs can create wide range of appli-	The UAVs are applicable for different cases such	The operational overheads of Blockchain may affect
	cations leveraging 5G IoT and on the other hand, from	as surveillance, and environmental protection with	the airtime of UAVs. The communication issues may
	infrastructure viewpoint UAVs can assist expansion of 5G	Blockchain.	cause physical damages to the devices.

ideal solution to enforce data privacy in the IoT context. Zhou et al. [48] proposed BeeKeeper, which utilizes homomorphic computation on the data without revealing any insights into the users who access data. The system was evaluated on the Ethereum Blockchain platform. Cha et al. [49] proposed Blockchain-connected gateways, which act as mediators between the IoT devices and the users.

E. Throughput

Besides the scalability problem of Blockchain, the throughput is another problem that is hard to tackle. The transaction throughput and latency are under consistent challenges, and as the size of transactions increases, in general, which are the hard problems that IoT system can not handle. While theoretical analysis of a platform may provide an idea about its performance, only practical implementation can provide a real-world use analysis. We can analyze the applicability of Blockchain systems based on the target use by considering the number of transactions necessary to be served in a target time frame. In the case of IoT devices, private Blockchains may be suitable, as the number of measurements for any single device will be small. Nonetheless, as we scale to larger IoT-based smart-world systems serving massively distributed devices, or big data systems that act on an unprecedented number of data items, the ability to apply Blockchain becomes more difficult. Gorenflo et al. [50] identified the performance bottlenecks in the consensus mechanisms and proposed architectural changes which reduces computational and other overheads to improve the throughput up to 20,000 transactions per second. In [51] some interesting new architecture and analytical studies are proposed to enhance the throughput and transaction latency of the Bitcoin Blockchain, however significant research still needs to be done to migrate that concept to the IoT/5G domains.

VI. CONCLUSION

With the evident popularity of IoT and the soon roll out of 5G technology, the paper brings to the lime light the challenges (some evident and some hidden) which will arise with the integration of the two. In the midst of other possible solutions, the paper expounds the use of Blockchain to mitigate many of those issues in the realm of 5G IoT. In particular, we emphasized on the opportunities and challenges that exist (and will show up in near future) with the use of Blockchain for the popular 5G-enabled-IoT uses case.

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